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Injury Potential from Carryover of Watermelon Herbicide Residues

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Studies were conducted to determine injury potential to rotational crops from carryover of herbicides used in watermelon production. Treatments included halosulfuron, ethalfluralin, and sulfentrazone alone; halosulfuron in tank mixtures with bensulide, clomazone, ethalfluralin, and naptalam; and a tank mixture of naptalam and bensulide. Sulfentrazone applied at 224 g ai/ha to watermelon severely reduced spinach emergence, but did not reduce emergence of broccoli, cabbage, or wheat. Residues of sulfentrazone applied to watermelon at 450 g/ha stunted growth of broccoli and cabbage and was the only treatment that reduced wheat stand. Injury to broccoli, cabbage, and spinach increased as the halosulfuron rate increased. Ethalfluralin did not reduce stand or cause injury to any of the four rotational crops. Naptalam plus bensulide did not reduce stand of the four crops and caused either slight or no injury. Residues of sulfentrazone and halosulfuron can injure vegetables following crops in which these herbicides are used, and caution should be taken particularly with spinach, broccoli, and cabbage in this respect.

Nomenclature: Bensulide; clomazone; ethalfluralin; halosulfuron; naptalam; sulfentrazone; broccoli, *Brassica oleracea* var. *botrytis* (L.) 'Everest', 'Green Sprouting Calabrese'; cabbage, *Brassica oleracea* var. *capitata* (L.) 'Early Jersey Wakefield'; spinach, *Spinacia oleracea* (L.) 'Cypress', 'F-380'; watermelon, *Citrullus lanatus* (Thunb.) 'Jubilee', 'XIT 101'; hard red winter wheat, *Triticum aestivum (L.)* 'Jagger'.

Key words: Emergence, stunting.

Summer watermelon crops produced in the south-central United States are often followed by fall rotational crops such as cool-season vegetables and winter wheat. When planning crop rotations, producers must consider the injury potential to subsequent crops from herbicide residues. Webster and Shaw (1996) reported reduced yield of wheat from pyrithiobac carryover from cotton. Johnson and Talbert (1993) reported both visual injury and reduced yield of spinach planted 3 to 4 mo after treatment with imazaquin and imazethapyr in southern pea (*Vigna unguiculata* L.). New herbicides for use in vegetable crops must be evaluated for effectiveness and safety to the crop in which they are to be used, as well as to rotational crops. The effect of sulfonylurea herbicides on rotational crops has been studied on various crop species including grain sorghum (*Sorghum bicolor* L.) (Rajvir et al. 2002), potato (*Solanum tuberosum* L.), and rutabaga (*Brassica napus Napobrassica* L.) (Ivany 1987). Kelly and Peeper (2003) observed injury and yield reductions from carryover of sulfosulfuron in grain sorghum and sunflower (*Helianthus annuus* L.) at a site with low soil pH and organic matter. Chlorimuron, a sulfonylurea herbicide applied to soybean (*Glycine max* L.), did not reduce wheat yield in Illinois (Krausz et al. 1994). Greenland (2003) reported 25 to 46% injury to cabbage from nicosulfuron carryover, but yields were not reduced.

Halosulfuron is a systemic, sulfonylurea herbicide (Vencill 2002) recently registered for vegetable crops. Recent studies have demonstrated the PRE effectiveness and crop safety attributes of halosulfuron alone at 18 to 54 g/ha and in combination with other herbicides on watermelon (Brandenberger et al. 2005). Sulfentrazone is a systemic, triazinone herbicide (Vencill 2002) being tested for use in minor crops, including cabbage (Smart et al. 2001) and watermelon (Brandenberger et al. 2005). Watermelon crops in Oklahoma and Arkansas are frequently followed in the fall by wheat or spinach and occasionally by cabbage and broccoli. The purpose of these studies was to determine the effect of halosulfuron, sulfentrazone, and halosulfuron in combination with other herbicides applied to watermelon on broccoli, cabbage, spinach, and wheat grown as rotational crops after watermelon.

Materials and Methods

Study Site Information. Field studies were conducted at agricultural experiment station sites at Bixby, OK, during 2001 and 2002; Lane, OK, during 2002; and Kibler, AR, during 2001. Soils at the two Oklahoma sites were a Severn very fine sandy loam [coarse-silty, mixed (calcareous), thermic Typic Udifluvents] at Bixby and a Stigler very fine sandy loam (fine, mixed, thermic Aquic Paleudalfs) at Lane. These soils were characterized by low organic matter (0.8% or less) and pH of 5.9 at Bixby and 7.0 at Lane. Soil at Kibler was a Roxanna silt loam (coarse-silty, mixed nonacid, thermic Typic Udifluvents) characterized by 0.8% organic matter and pH of 6.3. Preplant soil preparation was similar at Bixby, Lane, and Kibler, with plots being rotary mown to destroy existing watermelon vines and weeds, followed by soil tillage

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15 to 20 cm deep. At Bixby and Lane a tractor-mounted rototiller was used to till the soil in the same direction as the original crop rows. At Kibler, plots were disk-harrowed in the same direction as the original crop rows.

Experimental Procedures. Rotational crops included 'Cypress' and 'F-380' spinach in Oklahoma and Arkansas, respectively; 'Everest' broccoli at Bixby in 2001 and 'Green Sprouting Calabrese' broccoli at Bixby and Lane in 2002; 'Early Jersey Wakefield' cabbage at Bixby and Lane; and 'Jagger' wheat at Bixby and Lane. Rotational crops were direct-seeded into plots perpendicular to the original crop rows. Crops were planted September 11, 2001 (17 wk after herbicide treatment [WAT]) and September 10, 2002 (14 WAT) at Bixby; October 30, 2001 (26 wk after herbicide treatment) at Kibler; and October 18, 2002 (17 wk after herbicide treatment) at Lane. Plots at Bixby and Lane were planted with a four-row tractor-mounted pneumatic planter[1]. One row of each rotational species was planted with 46 cm between rows and 2.5 cm between seeds. Plots at Kibler were seeded to six rows of spinach with a research cone planter[2] with 23 cm between rows and 2.5 cm between seeds. No weed control measures or supplemental fertilizers were used in rotational crop plots. The only crop input used was overhead sprinkler irrigation at all sites to ensure adequate moisture for seed germination.

Treatments at each study site were arranged in a randomized complete block design with four replications. Plots at Bixby and Lane were 0.5 m wide by 3 m long for each rotational crop species, and plots at Kibler were 1.4 by 3 m. Herbicides and rates applied PRE to watermelon crops the previous spring are listed in Table 1. All herbicides except sulfentrazone were included at Bixby in 2001; all treatments were included at Bixby in 2002; all but halosulfuron at 18 g ai/ha and the two combinations of clomazone plus ethalfluralin plus halosulfuron were included at Lane in 2002; combinations including clomazone plus ethalfluralin plus halosulfuron were included at Kibler in 2001. Herbicides were applied with a CO_2-pressurized four-nozzle[3] hand-boom sprayer calibrated to deliver 187 to 281 L/ha at pressures of 124 to 221 kPa.

Data Collected and Statistical Analysis. Visual ratings were recorded for each rotational crop as percentage emergence and injury to the crop. Ratings were expressed on a 0 to 100% scale, in which 0 represented no crop emergence or stunting and 100 represented complete emergence on the basis of one plant every 2.5 cm or death of all plants. Initial injury ratings were recorded 18 to 20 WAT to the watermelon crop, and final ratings were 23 to 29 WAT. All data were analyzed using analysis of variance with PROC MIXED in PC SAS software Version 9.2.[4] Percentage data were transformed using the arcsine square-root transformation. A split-plot arrangement in a randomized complete block design was assumed, with replications within locations serving as blocks, and time serving as the split unit factor (when appropriate). For the analyses involving time, simple effects of treatment at a given time period were analyzed with a SLICE option in an LSMEANS statement. When the SLICE option was significant at a 0.05 significance level, multiple comparisons for treatment were performed using a DIFF option (i.e., protected pairwise *t* tests) at a 0.05 significance level.

Results and Discussion

Effects of Herbicide Residues on Broccoli. Broccoli emergence was not reduced by herbicide residue when compared to the nontreated check (Table 1). Emergence of broccoli ranged from 84% for halosulfuron at 27 g/ha to 100% with sulfentrazone at 224 g/ha. However, halosulfuron reduced broccoli height, and leaves were fewer and smaller (data not shown). Stunting at 18 to 20 WAT was numerically highest in plots treated with halosulfuron alone at 36 and 54 g/ha compared to the nontreated check. At 23 to 29 WAT, most treatments containing halosulfuron at 27 g/ha or higher stunted broccoli. At both rating times, stunting increased as the halosulfuron rate increased from 18 and 36 g/ha.

Effects of Herbicide Residues on Cabbage. Sulfentrazone at 450 g/ha and the tank mixture of clomazone, ethalfluralin, and halosulfuron at 170 + 630 + 36 g/ha, respectively, were the only treatments that significantly reduced cabbage emergence compared to the nontreated check (Table 1). Although emergence appeared to decrease with increasing rates of halosulfuron, no significant reductions in emergence were recorded for treatments with halosulfuron alone at 36 and 54 g/ha. Injury to cabbage was observed as crop stunting and consisted of height reduction and fewer and smaller leaves. Cabbage was stunted at 18 to 20 and 23 to 29 WAT from halosulfuron alone at 36 and 54 g/ha, sulfentrazone at 450 g/ha, and both tank mixtures containing clomazone, ethalfluralin, and halosulfuron. By 23 to 29 WAT, tank mixtures of halosulfuron with either naptalam or bensulide were no more injurious to cabbage than halosulfuron alone at 27 to 54 g/ha. However, adding clomazone plus ethalfluralin to halosulfuron increased injury over that of halosulfuron alone at 27 g/ha 18 to 20 WAT. Sulfentrazone at 450 g/ha reduced stand of cabbage but not broccoli and appeared to be more injurious to cabbage (30% stunting) than to broccoli (16% stunting). This is not surprising because even cultivars within the same genus and species can exhibit different responses to sulfentrazone (Dayan et al. 1997).

Effects of Herbicide Residues on Spinach. Emergence of spinach was severely reduced by residues of sulfentrazone (9% emergence) and moderately reduced by halosulfuron at 36 g/ha or higher (approximately 74% emergence), compared to 92% emergence for the nontreated check (Table 1). Injury from sulfentrazone and halosulfuron was observed as stunting including a reduction in overall plant height and fewer leaves that were smaller in size (data not shown). Sulfentrazone caused considerable stunting (57 to 89%) to spinach at 23 to 29 WAT. Halosulfuron caused 10 to 48% stunting in spinach, depending on rate. Sugar beet (*Beta vulgaris* L.), a plant species related to spinach, was injured by chlorsulfuron residues following application to wheat (Brewster and Appleby 1983). In studies by Moyer (1995), sugar beet was significantly injured by residues of the sulfonylurea herbicides of tribenuron and thifensulfuron. Spinach was not stunted by

Table 1. Percentage emergence and stunting to broccoli, cabbage, spinach, and wheat rotational crops following herbicides applied to a previous watermelon crop.[a,b]

		Broccoli			Cabbage			Spinach			Wheat		
		Emergence[c]	Stunting[d]		Emergence	Stunting		Emergence	Stunting		Emergence	Stunting	
Herbicide	Rate	18–20 WAT	18–20 WAT	23–29 WAT	18–20 WAT	18–20 WAT	23–29 WAT	18–20 WAT	18–20 WAT	23–29 WAT	18–20 WAT	18–20 WAT	23–29 WAT
	g ai/ha	%											
Nontreated	0	92 abc	0 c	0 e	87 ab	0 c	4 e	92 ab	0 d	0 g	86 ab	0 a	2 a
Halosulfuron	18	95 ab	3 c	8 cde	95 a	3 c	4 e	97 ab	8 cd	10 fg	89 ab	1 a	3 a
Halosulfuron	27	84 c	12 bc	14 abcd	88 ab	8 bc	14 bcde	76 bcd	30 bc	33 cdef	88 ab	1 a	3 a
Halosulfuron	36	87 c	32 ab	25 ab	83 abc	19 ab	27 abc	75 cd	26 bc	37 cd	88 ab	0 a	2a
Halosulfuron	54	86 c	35 a	29 a	77 bc	36 a	29 ab	73 d	39 b	48 bc	93 ab	0 a	2 a
Halosulfuron plus ethalfluralin	27 840	91 bc	17 abc	9 cde	90 a	13 bc	14 bcde	87 bcd	26 bc	27 def	92 ab	0 a	0 a
Halosulfuron plus ethalfluralin	27 1,680	91 bc	11 c	13 bcd	89 ab	9 bc	13 cde	99 ab	23 bc	25 def	97 a	2 a	3a
Halosulfuron plus naptalam	27 3,370	94 abc	12 bc	14 abcd	88 ab	11 bc	18 abcd	88 abcd	24 bc	36 cde	97 a	1 a	2a
Halosulfuron plus bensulide	27 5,610	94 abc	9 c	10 bcd	91 a	9 bc	18 abcd	90 abc	22 bcd	36 cde	92 ab	1 a	4a
Naptalam plus bensulide	3,370 5,610	95 ab	0 c	3 de	88 ab	2 c	15 bcde	93 ab	0 d	12 fg	90 ab	4 a	1 a
Ethalfluralin	1,680	97 ab	0 c	4 cde	96 a	0 c	6 de	100 a	0 d	12 fg	92 ab	3 a	3 a
Sulfentrazone	224	100 a	0 c	3 de	93 a	0 c	5 de	9 e	83 a	57 b	91 ab	0 a	1 a
Sulfentrazone	450	95 ab	8 c	16 abc	72 c	29 ab	30 ab	9 e	83 a	89 a	55 c	15 a	9 a
Clomazone plus ethalfluralin plus halosulfuron	170 630 27	86 c	30 ab	31 a	75 bc	32 a	25 abc	84 bcd	32 bc	31 cdef	84 ab	3 a	2 a
Clomazone plus ethalfluralin plus halosulfuron	170 630 36	86 c	28 abc	26 ab	69 c	28 ab	35 a	76 bcd	40 bc	43 bcd	89 ab	0 a	2 a

[a] Rotational crops were direct-seeded into herbicide plots from a previous watermelon crop 14 to 26 wk after herbicide treatments (WAT) were applied to the plots; 18 to 20 and 23 to 29 WAT are the number of weeks from herbicide applications to evaluation of rotational crops.

[b] Untransformed means are presented in each column with significance on the basis of transformed means; means followed by the same letter are not different at 0.05 level of significance.

[c] Emergence was expressed on a 0 to 100% scale, in which 0 represented no crop emergence and 100 represents complete emergence on the basis of one plant every 2.5 cm.

[d] Stunting was expressed on a 0 to 100% scale, in which 0 represented no stunting and 100 represents complete death of all plants.

residues from ethalfluralin alone, naptalam plus bensulide, and halosulfuron alone at 18 g/ha compared to the nontreated check at 23 to 29 WAT.

Effects of Herbicide Residues on Wheat. Wheat emergence was reduced significantly only by residues of sulfentrazone at 450 g/ha (55%) (Table 1). Wheat was not visibly injured by residues of any of the herbicides, including the sulfonylurea herbicide halosulfuron. Work by Krausz et al. (1994) indicated that wheat yield was not affected by residues of chlorimuron, another sulfonylurea herbicide. The authors would surmise that wheat responded in a similar manner to the sulfonylurea herbicides included in this study.

Spinach was the rotational crop for which emergence was most affected by herbicide carryover in these studies; other crops were affected, but to a much lower extent. Spinach was particularly sensitive to sulfentrazone. Emergence of wheat and cabbage was also reduced by sulfentrazone at 450 g/ha, but not from the 224 g/ha rate. Similarly, Miller (2003) reported no loss of cabbage stand from residues of sulfentrazone at 280 g/ha. Injury to rotational crops from sulfentrazone and halosulfuron after emergence was exhibited as stunting by spinach, broccoli, and cabbage, but no injury was observed in wheat. Spinach was significantly stunted from sulfentrazone and most halosulfuron treatments. Broccoli and cabbage were most sensitive to halosulfuron and sulfentrazone alone at higher rates and to tank mixtures of clomazone, ethalfluralin, and halosulfuron. Although Miller (2003) reported no detrimental effects to spinach, that crop was planted approximately 12 mo after sulfentrazone application. Other researchers (Novosel et al. 1995; Shinn et al. 1998) reported significant levels of crop injury and resulting yield loss from the carryover of sulfonylurea herbicides in sugar beet and canola (*Brassica napus L.*), a crop species related to both broccoli and cabbage. In preliminary work in Oklahoma, total loss of spinach yield occurred when the sulfonylurea herbicides imazosulfuron and trisulfuron sodium were applied PRE in spinach (Brandenberger et al. 2002, 2004). Although our studies did not record yield data, we would deduce from previously mentioned works that yield would be reduced in spinach from carryover residues of halosulfuron and sulfentrazone alone and from tank mixtures containing halosulfuron. Similarly, cabbage and broccoli yields would likely be reduced from carryover residues of halosulfuron and sulfentrazone at higher rates and the two tank mixtures containing clomazone plus ethalfluralin plus halosulfuron. We would recommend additional study to determine the length of plant-back intervals for the three vegetable crops included in this study when following both halosulfuron and sulfentrazone.

Sources of Materials

[1] Model NG Plus, ATI., Inc. 17135 West 116th Street, Lenexa, KS 66219.

[2] H and N Equipment, 13915 W. 53rd Street, North Colwich, KS 67030.

[3] DGTeeJet 11004, DGTeeJet 11003, TeeJet 8002 VS spray nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900.

[4] SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513.

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